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Earth System Dynamics
Discussions

Interactive comment on "Earth System Economics: a bio-physical approach to the human component of the Earth System" *by* Eric Galbraith

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Thanks to Referee 2 for the incisive questions and comments, which have been very helpful in planning how to improve the paper in a thorough revision. Most importantly I plan to rewrite much of parts 1 and 2 to address shortcomings in the presentation, and will also re-orient and streamline the model discussion. Please see below for a point-by-point response to the review (referee comments in italics).

The paper " Earth System Economics: a bio-physical approach to the human component of the Earth System" is an interesting and thought-provoking article.

Thank you, I am glad it was thought-provoking.

However, even after reading the paper, I am not clear on why one needs to represent

humans in this fundamental way in a coupled human-Earth system model. Why aren't traditional economic models or even agent-based models sufficient? Can you replicate reality with such a fundamental approach? It seems to me that it would be better to prove that such a framework works for representing human systems before you couple it to another complex system like the Earth system.

I appreciate the request for further explanation of the model motivations, which echoes some of the comments of Referee 1. As I wrote in the response to his/her comments, there continues to be a wall between natural and social sciences, that blocks development of a truly unified framework for understanding the human-Earth system. Without this, it is difficult to grasp the big picture, and to share insights across domains.

This is not to say that traditional economic models or agent-based models don't play very important roles. They have been, and will undoubtedly continue to be, very successful. The present approach is proposed as an alternative, complementary one - and not primarily to replicate reality, but to analyze, develop and test hypotheses about how the human-Earth system functions.

In addition, the illustrative zero-dimensional example included here was only intended to show that the approach is workable, as suggested. The underlying motivation here is to provide relatively a simple, but inclusive approach, intended to help in understanding the full system. The complexity of the human-Earth system is precisely the reason why multiple simple, inclusive approaches are necessary.

Line 32: "limited or no spatial resolution" is unclear and incorrect in some cases (e.g., IMAGE has a gridded land use module)

Thanks for pointing this out, I will correct it.

Line 42: I'd suggest noting the exceptions to this as there are a handful of examples of steps taken in the citations you list here.

Thanks, it is a good point, and 'steps' is admittedly an imprecise term. I would like to

avoid going into a long literature review to maintain readability, so will rephrase this to avoid implying that no steps have been taken.

Line 60-62: What does "by the meat" mean?

This quote is a colourful phrase cited by the cognitive philosopher Andy Clark to capture the counterintuitive fact that the physical 'meat' of our brains is responsible for generating all the remarkable features of human consciousness. I will either explain better, or remove the phrase.

Section 2.4: From this section, it seems that you are using the word "economics" outside of its common definition. I'd suggest clarifying that at the first use of the word in the introduction. Right now, the introduction doesn't discuss economics other than to introduce the term ESE.

This is an excellent suggestion, I will introduce this distinction up front.

Section 2.5: How does this relate to agent-based modeling?

Great question. An early draft included a section on agent-based modeling, which I removed. Essentially agent based modeling primarly aims to resolve emergent properties from rule-based interactions between agents. In the ESE approach, populations do not move or interact, they are embedded within the physical Earth framework and evolve over time. As such, the emergent properties are the consequences of dynamical processes within the populations, including fluxes between them. I will elaborate on this in the revised version.

Line 240: I understand your quest for "real physical constraints", but does constraining the metaconnectome impose meaningful constraints on variables of relevance to the Earth system? If not, then real physical constraints there have little value in a coupled human-Earth system model.

I can understand the source of this skepticism, which has echoes in the reaction of Referee 1. What didn't come across was that the physical neurological basis is in-

tended as a conceptual underpinning and long-term goal, rather than an immediately workable strategy to provide meaningful new constraints. Section 2.1 of the submitted manuscript was intended to convey this, but I think it was not prominent enough. When revising the manuscript I will be sure to highlight the continued need for physically-inspired approximations, as frequently applied throughout Earth System Modeling.

Section 3.1.2: Time allocation seems like a physical constraint more directly linked to the Earth system (e.g., a limit on the amount of time one can spend driving). However, even this constraint would only be loosely coupled with variables of relevance to the Earth system. One could theoretically consume a lot of electricity (and thus produce a lot of emissions) while sleeping. Also, in this section, it might be valuable to mention the existing literature on time allocation. There is an economic literature on labor-leisure trade-offs and the transport literature often factors in the value of one's time when estimating modal shifts.

I agree that time allocation is more immediately obvious as a focal point than the connectome. I will revise the manuscript to highlight time allocation more prominently as the core foundation of ESE. I also agree it's a good idea to include some further discussion of the prior literature on time use. (Also, please note that humans do not consume electricity in this framework, as biological entities they only consume food, water and oxygen. Things consume electricity. I will highlight this important distinction in the revised paper.)

Line 276-278: I think this is a fundamental problem with this paper. It isn't clear that this approach could capture any particular period in history. I think that needs to be demonstrated in order for the approach to be useful. Right now it just seems like a complex way of representing humans, but hasn't been shown why this is needed or that it will work.

I am somewhat surprised that the referee interprets the ESE approach as a complex way of representing humans. From my perspective, it proposes a simple hierarchical

structure that allows many possible levels of aggregation, an approach that is generally very useful for representing complex systems. But it has been said that complexity is in the eye of the beholder.

More importantly, the initial manuscript did not sufficiently distinguish between the general approach and the particular model illustration, a confusion that also contributed to the initial response of Referee 1. Lines 276-278 refer only to the illustrative model, not the general approach. The revised manuscript will make this much clearer.

Section 4: Are there sources for the equations? How much does the precise functional form matter? For example, is equation 6 a standard way of representing the connectome?

Thanks for requesting further detail on the equation sources. These will be more fully elaborated in the revision, and I will also provide an updated version of the model which focuses more on the salient points, in the hope of generating fewer distractions.

Lines 435-440: A lot of food waste in the developed world today has nothing to do with consumption by other animals, bacteria, etc. The total amount of food produced vastly exceeds the amount needed for metabolic function in these countries. How is that accounted for in your model? Does this argue that metabolic function is not actually a binding constraint on food production?

I had elaborated on this in an earlier draft, but thought it was too technical, so removed it from the paper. One could conceive of food waste in multiple ways, but the most straightforward way to conceptualize the food waste would be as a factor that raises the food requirement: essentially, to treat the post-harvest waste of edible food as an additional metabolic cost. Thus, if food waste were 20 % of all edible food, the modified 'metabolic cost' would be 120 % of the actual metabolic cost. A similar, though less frequently discussed term, is the egested mass. Presumably this is not discussed as widely because it's not a polite topic, but it is on the same order of magnitude as the food waste term. At any rate, both can be assumed part of the uncertainty in the

'metabolic cost'. I will reinstate this discussion to the revised text if space allows.

Thanks again for the very helpful comments and suggestions.

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